Internal Research Report / Rapport Interne de Recherche n° RR/12-02

Application of an Enterprise Modelling approach to deploy Systems Engineering processes in large

Clémentine Cornu, Vincent Chapurlat, Jean-Marc Quiot, François Irigoin

Ecole Nationale Supérieure Mines Alès -- 6 avenue de Clavière, 30319 Alès cedex
LGI2P - Laboratoire de Génie Informatique et d'Ingénierie de Production, Parc scientifique Georges Besse, F30035 Nîmes

Application of an Enterprise Modelling approach to deploy Systems Engineering processes in large organizations

Clémentine Cornu[*1], **Vincent Chapurlat**[**], **Jean-Marc Quiot**[*] **and François Irigoin**[***]

* Eurocopter, ETZR, Aéroport International Marseille Provence, 13725 Marignane Cedex – France, email:{Clementine.Cornu, Jean-Marc.Quiot}@eurocopter.com

** LGI2P - Site de l'Ecole des Mines d'Alès, Parc Scientifique George Besse, 30035 Nîmes Cedex 1 - France, email: Vincent.Chapurlat@mines-ales.fr

*** Mines ParisTech - CRI, 35 rue Saint Honoré, 77305 Fontainebleau Cedex - France, email: Francois.Irigoin@mines-paristech.fr

Abstract

Enterprise Modelling (EM) enables the representation of companies' activities, of their resources along with their roles and responsibilities in order to share the company's knowledge and support performance analysis. For this, EM promotes various concepts, techniques, frameworks, modelling languages and tools today widely used in companies. Currently, even a partial model of an enterprise constitutes a way to communicate, to share advices, to analyse and to make decisions. Therefore, EM appears to be a privileged tool to support any business change management.

In a complementary way, Systems Engineering (SE) is a tried and tested methodological approach to design and test new products whatever their complexity or nature. Nowadays SE is considered in industry as a competitive and structured approach enabling a company to manage design activities and more generally to improve its capacity and ability to design complex systems efficiently. SE acts as a model-based engineering approach and promotes to this end a set of standardized collaborative processes, modelling languages and frameworks.

Thus, when considering large companies designing complex systems such as a helicopter manufacturer, first it appears critical to be able to adapt processes proposed by SE standardization according to the business specific needs. This tailoring must be guided in order to consider the inherent complexity of the organization, the various human actors' profiles and skills, tools and stakeholders involved in the design of new products. As they all have to communicate and interact efficiently together their abilities and capacities to be interoperable *i.e.* to really work together should be analysed and improved accordingly before going further. Then, it appears necessary to prepare the company for the required changes, and to deploy *in situ* the adopted SE processes taking into account not only company's classical constrains and objectives but also the current level of interoperability of its elements. Finally, company managers must become able to control and adjust these processes from the cradle to the grave according to feedbacks from their stakeholders. To support all these activities, Enterprise Modelling (EM) provides several techniques, modelling languages, reference models and interoperability assessment methods which have been adapted and applied in this research work.

The purpose of this article is threefold: 1) to provide a state of the art in interoperability, Systems Engineering (SE), and EM to illustrate how these disciplines are interrelated, to identify the needs they imply in the deployment, to discuss lacks in existing works considering these needs and thus to formulate how we aim to meet them, 2) to present an approach based on EM helping companies to lead changes required to apply SE principles and aiming to promote interoperability; and 3) to introduce the modelling environment proposed to support the approach including an ontology, an extension of BPMN 2.0 and software tools.

Keywords

Systems Engineering, Enterprise Modelling, Process deployment, Interdisciplinary design, Interoperability, AS-IS/TO-BE/IDEAL/IMPLEMENTATION models

[1] Corresponding author: Clementine.Cornu@eurocopter.com, phone. (+33) 442 850 00 40

1. Introduction

Given the increasing competition existing on markets, companies have now a vital need to provide innovative products with the shortest design cycles in order to gain profitability and to differentiate themselves from their competitors who have abilities to quickly produce cheaper copies. They must also deal with global partnerships that are now quite inevitable considering the globalization phenomenon. In this context and considering its results, Systems Engineering (SE) defined as "*a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system*" [42] can be seen as a magic bullet since it acts as an organized frame for design activities. However, to apply SE principles as described in standards may be very challenging if the company does not create products from scratch, but develops new products on the basis of existing products or components [39]. The will of developing new innovative products from scratch involves then to lead a change in the company's way of designing products and to introduce adapted new processes. It is a hard task raising many difficulties and questions such as:

- The enterprise may assume that the deployment of SE processes requires some pre-requisites to be successful. But what are they? How to know if the company fulfils all these success criteria and is mature enough to face the deployment?
- Many standards are available and provide companies with various definitions of SE, associated processes and best practices, but they are not always consistent and often overlap. Then, how to know which standard best fits the company's needs and can be used as a basis for the methodological referential of the company? Furthermore, standards provide high-level descriptions of processes that aim to fit to most of companies. Accordingly, proposed processes must be tailored to consider company's specificities, business area, environment and projects. They must also be enriched with details to make them easily applicable. Some tips are provided in standards [26][2] to operate this tailoring but that is, once again, high level descriptions which must themselves be tailored… Then how to proceed to this tailoring?
- Except if the company employs a consultant or somebody who already experienced a Systems Engineering (SE) processes deployment, there is no deployment method formalized to help companies deploy SE. Then how to proceed if companies want to deploy SE by themselves?
- Are there any computer tools available to support this deployment? If not, what does the company need?

In addition to these questions/difficulties, we make some hypotheses inducing new ones:

- We assume that processes should be described using models in order to make their understanding easier and to enable automatic execution. But standards rarely describe processes using models and if they do [42][2], they do not use standard modelling languages... Then, what kind of models should be build? With which modelling language? Using which semantic concepts? Etc.
- We assume that a deployed process should be controlled by another process that we called *"management process"* which should be deployed at the same time. However standards do not describe this kind of processes but only project management processes. Furthermore deployment processes are not addressed at all. So, companies must find out by themselves how to manage and deploy the new processes they want to introduce in their organizations.
- We assume that interoperability, *i.e.* the "*ability of companies and entities within those companies to communicate and interact effectively*" [3] is a key factor for the success of the deployment. But how to consider it? How to assess it? How to improve it within the company?

This paper aims to provide practical answers to these questions/difficulties in the context of the deployment of SE in large companies designing complex systems such as a helicopter manufacturer where design practices are settled but not necessarily standardized. However, this paper does not aim to settle difficulties related to social sciences such as psychological barriers, human relationships etc. (see [5] for more information about these topics). Thus, after a short analysis of the state of the art about SE and Enterprise Modelling (EM) in Section 2, this article presents in Section 3 an approach based on EM helping companies to lead changes required to apply SE principles and aiming to promote interoperability. Finally, Section 4 introduces the modelling environment proposed to support the approach including a meta-model, an OWL (Ontology Web Language) ontology, an extension of BPMN 2.0 and software tools.

2. Needs and discussion

This section details the needs implied by the deployment of Systems Engineering (SE) processes, provides some elements of state of the art in the various fields impacting it, and introduces contribution of the research work. For this, we present first the interoperability hypothesis and the classification of obstacles that prevent it. Then, the SE discipline, its needs for the deployment and existing works that could be useful for it are introduced. Last, it shows when, where and how Enterprise Modelling (EM) concepts and appropriate modelling techniques can be used to support the proposed deployment approach.

2.1. Hypothesis of work: the consideration of interoperability barriers

By hypothesis we have assumed that interoperability conditions the success of the SE processes deployment approach. Many efforts have been done in the last ten years to define interoperability. This research considers the definitions proposed by INTEROP-NOE project [24] albeit it focuses on the interoperability of computer systems. This project has classified interoperability problems into three *"interoperability barriers"* defined as follows:

- Technological barrier defined as the "*lack of a set of compatible technologies which prevent collaboration between two or more systems*". Thus, technological problems include all technical difficulties that prevent computer systems to exchange and use information exchanged.
- Conceptual barrier defined as the "*syntactic and semantic differences of information to be exchanged as well as the expressivity of the information*" with expressivity defined as "*ability to represent and communicate knowledge in a pragmatic and easy to understand way*". In this study, we consider all the five levels defined in [16] as elements for conceptual interoperability.
- Organisational barrier defined as the "*definition of responsibility and authority so that interoperability can take place under good conditions*". Thus, this barrier is related to the behaviours of actors, processes and organisational units.

2.2. Systems Engineering

SE is defined by [2] as: "*an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all stakeholders."* So SE is as at the junction of three disciplines: engineering, management and system reasoning [5]. The two main objectives of SE [37] are then: 1) the improvement of the current engineering techniques used to create the system-of-interest (SOI) *i.e.* the final product or service that the organisation wants to produce, and 2) the development and improvement of the way the coordination between all the stakeholders implied in the SOI life-cycle is done. These objectives are materialized in standards by two types of processes: management and technical processes. According to these standards and to [4], Systems Engineering (SE) deployment in a company consists first in the institutionalization of processes in order to improve its professional activities and results, and second in leading the change [30] so that processes execution is effective in the different projects. Therefore, to succeed in its deployment, we have identified that the company needs to:

- Specify the expectations of the deployed process, of the company itself regarding its current practices, usages and organisation in terms of resources, activities, expected results, and stakeholders having to be involved in technical or management process.
- Specify conditions and constraints for success that should be satisfied to start a deployment. This requires a mean to assess company's maturity to face a deployment and a mean to assess its interoperability level concerning:
    - Conceptual interoperability. The company needs a common language *i.e.* a communication basis for all stakeholders involved in the deployment and/or in the processes to deploy. So concepts, relationships and their semantics have to be specified.

- Technical interoperability. The company needs to share relevant tools supporting the deployment and the execution of processes to deploy.
- Organisational interoperability. The company needs to identify roles, expectations and usages for the deployment and processes to deploy to define then actors and business units needed.

- Identify SE best practices that could be applied in the company *i.e.* to specify processes models describing what should be pragmatically deployed and how it can be done.
- Be guided in its deployment *i.e.* to specify a methodological guide, related and directly applicable in the company, explaining the steps required to deploy SE processes.

There are various contributions in SE that address different problems appearing when facing these needs. First of all, [4] identifies the following set of necessary conditions for the success of SE deployment: strong involvement of the hierarchy, progress objectives shared by all, effective allocation of resources required, forming and training of a credible team responsible for the project in charge of company's evolution and supported by the change leaders in the units concerned. Second, various standards highlighting different points of view about SE are available as summarized in Table 1 in the case of a helicopter manufacturer. This table sorts these standards considering their prescriptive (*i.e.* if their requirements are mandatory when used as a basis for conformance assessment) or descriptive nature (*i.e.* if their propositions are provided as advice) [11]. To take into account these standards is necessary for four reasons. First, they provide processes reference models. Even if some of them are described with a high-level of abstraction and are not tailored to the company, they are sufficient to consider interdisciplinary nature of Systems Engineering (SE) and can be completed with domain specific standards. Second, standards result from discussions and represent a convergence between industrial and academic points of view. Third, the compliance to a standard may be an advantage for trade since it may inspire confidence to partners. Finally, a standard can be used as the common reference for the company and its partners, improving then their capacity to be interoperable. Of course, standards are not without limitations [41][37]: conflicts and overlapping, possibility of multiple interpretations of the text, non-automated audits, non-reproducibility of responses, heavy validation, difficulty to establish traceability, limited reuse, and difficulty to find information. Besides, they do not meet some of priority needs we have identified. First, the proposed processes models are not established using a common process modelling language, and less an acknowledged international one. It remains then difficult to make possible future use of workflow engines respecting these standards. Second, although it is crucial to prevent difficulty in application and human rejection, they are not practicable, instinctual and communally adaptable [5]. Finally, even if SE standards like [26][2] sometimes provides definitions of "*tailoring processes*" that aim to help companies adapting the generic processes defined, they are high-level ones and the tailoring is not really guided.

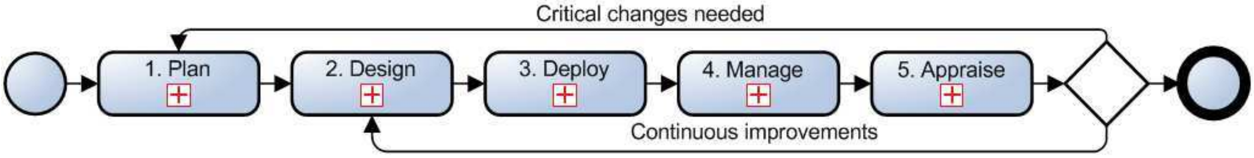
Name		Nature	Application field
EIA 632	[15]	Prescriptive	Generic
IEEE 1220	[23]	Prescriptive	Generic
ISO/IEC 15288	[27]	Prescriptive	Generic
ISO/IEC TR 19760	[25]	Descriptive	Generic
ISO/IEC TR 24766	[28]	Descriptive	Generic
ISO/IEC TR 90005	[27]	Descriptive	Generic
INCOSE SE Handbook	[2]	Descriptive	Generic
NASA SE Handbook	[42]	Descriptive	Aerospace
BNAE RG.Aéro 000 77	[9]	Descriptive	Aerospace/Aeronautics
BNAE RG.Aéro 000 40 A	[8]	Descriptive	Aerospace/Aeronautics
ECSS-E-ST-10C	[14]	Descriptive	Aerospace
Guide for ITS	[46]	Descriptive	Transport

Table 1: Overview of SE standards usable by a helicopter manufacturer

Next, we have identified that companies need to be guided in their deployment of SE processes. In fact, two scenarios are possible. First scenario, the company has not internal resources with required skills and therefore employs a consultant. Each one has its own legitimate and proven approach. However, despite the effectiveness of these approaches, there are no public documents formalizing them… Second scenario, the company has qualified resources. In this case, in order not to get lost in the complexity of the problem, the company needs a formalised dedicated deployment methodology. Few deployment methodologies are easily and freely accessible such as the next ones. First [4] recommends starting by deploying the processes of "*requirements engineering*" and "*configuration management*" since they are structuring for other processes to deploy and essential in the Systems Engineering (SE) approach. For this, authors encourage companies to perform the following steps: 1) Assess the maturity of processes, 2) Identify priority axes of improvement and objectives to reach, 3) Using existing practices to define and execute a plan of progression meeting previously defined objectives, and 4) Assess results. Even if this approach deserves to be mentioned since only few deployment methodologies are available in the literature, this approach is provided with too few details. [37] provides a second approach where a generic process of formalization of SE normative recommendations leads to the development of formal models. The author recommends first to build a model of the standard. For this, he recommends: 1) modelling the processes, 2) modelling the system structure, 3) modelling the system life cycle, and 4) analysing the models obtained. Next, the author recommends developing a "*business model*" without more details and adapting it to a "*project model*". For this, a list of applicable standards must be established and their impacts on the generic process model must be specified. This work presents the advantage to be based on EM and to encourage the capitalization and reuse of models. Furthermore, as promoted by SE, it encourages the use of requirements to accurately define the expectations of the project before defining the model of the project. However, the approach remains textual and few details are given to make it directly applicable. Besides, in this work, standards are considered as "*absolute models*" but they result from a consensus between people from both industrial and academic fields. So, a company having good practices or specificities not taken into account or even contradictory with the standard should not be compliant with standards if it is not in its interest from on the long view.

Finally, a third work that can be used as a deployment methodology is [43]. Indeed, it promotes a generic cycle of process management that summarizes various positions [32][45][20][49][22][21][7] about Business Process Management and can be applied in this context (see Figure 1). This generic cycle is broken down making appear activities to consider risks when defining and managing processes. However, this methodology has been thought to improve existing processes. So, activities are missing to tailor processes provided in standards. Furthermore, only few details and models are given, making the application of the approach difficult.

Figure 1: Generic cycle of process management defined in [43]



Last, we have identified that a company has to consider interoperability barriers for its deployment. To do that [5] presents means to improve conceptual and organizational interoperability since it identifies and characterizes a taxonomy of the work products mentioned in [26]. Furthermore, a meta-model relative to human competence and capabilities is proposed. Moreover, four major roles in the application of Systems Engineering (SE) principles are identified: *business* and *project managers* who are mainly involved in management processes, *systems* and *specialists engineers* who are mainly involved in engineering processes. These roles can be completed with those defined in [40]: *Requirements Owner, System Designer, System Analyst, Validation/Verification Engineer, Logistics/Operations Engineer, Glue Among*

Subsystems, Customer Interface, Technical Manager, Information Manager, Process Engineer, Coordinator, and *Classified Ads SE.*

In all cases and all proposed approaches, lots of concepts, methods and tools coming from Enterprise Modelling (EM) domain are required.

2.3. Enterprise Modelling

EM is defined as "*the art of externalizing enterprise knowledge which adds value to the enterprise or needs to be shared. It consists of making models of the structure, behaviour and organization of the enterprise*" [47]. Thus, the use of models should be considered in the deployment since they enable [37][5][12]:

- assisting the deployment team in the development and structuring of ideas,
- supporting communication between deployment stakeholders by providing a model of cooperation agreed by all and by designating a common language,
- facilitating the monitoring and the execution of the deployment project and processes to deploy by formalizing roles and responsibilities,
- defining the organizational capabilities and skills development,
- performing activities of verification and validation of the modelled entity (organisation, process to deploy, ...) before its real implantation or any decision,
- understanding and analysing constraints due to possible divergences between missions of the enterprise and its actors' expectations, constraints due to interactions between resources, flows, activities and processes and constraints due to interactions between the enterprise and its environment (suppliers, customers and other partners).

Consequently, we propose to organize the use of models thanks to three well-known enterprise models [12]:

- The AS-IS model that describes the current situation having to be taken into account to achieve the intended objectives,
- The TO-BE model that describes the structure, functions and behaviours of the solution that has been designed,
- The IMPLEMENTATION model that describes how the TO-BE model can be effectively deployed in the real environment *i.e.* describes the required programme and sub-projects to be done, planning, equipment, devices and human resources to involve.

Moreover, the three-axis reference framework proposed in [1] can be used in order to help the company conduct modelling steps in an orderly and structured way and without forgetting any aspects of the problem. This framework includes:

- Four views through which the objectives of the project must be considered: *functional*, *resource*, *information* and *organization views*,
- Three levels of abstraction: *generic*, *partial* and *particular*.
- Seven steps: *Identification*, *Concept*, *Requirements*, *Design*, *Implementation*, *Operation*, *Decommission*. During the *Identification* and *Concept* steps of the project, the AS-IS model is built. Then, during the *Requirements* and *Design* steps, the deployment team should build the TO-BE model. Finally, during the *Implementation* and *Operation* steps, the IMPLEMENTATION model is defined.

Finally, various standardised modelling notations and languages can be used to describe the required models. Indeed, they enable solving various lacks concerning semantic interoperability, but also formalising and facilitating automation. For this, [37] recommends the use of SPEM (Software Process Engineering Metamodel) [34], a meta model used to describe a concrete software development process as modelling language. In enterprise modelling domain we suggest using BPMN 2.0 (Business Process Modelling Notation) [36] since it is an acknowledged standard compatible with BPEL (Business Process Execution Language) [33]. Thus it enables execution and control of a given process. However, BPMN presents some limitations. For example, a *Pool*[2] is defined as the graphical representation of a *Participant* in a collaboration,

[2] *This police* is used to identify vocabulary from BPMN 2.0

but a *Participant* can be a specific *PartnerEntity* (e.g., a company) or a more general *PartnerRole* (e.g., a buyer) [36]. Therefore, a *Pool* embraces both roles and resources concepts and may lead to misunderstandings *i.e.* to semantic interoperability problems. Moreover, roles and responsibilities played by resources should explicitly appear to improve organizational interoperability. By the way, another modelling difficulty appears when an activity must be performed by more than one resource/role. Indeed with the current version of BPMN, we are constrained to group the set of resources/roles performing the activity into a global entity but that does not contribute to clarity and expressiveness of models and therefore to semantic and organizational interoperability. Finally, some notions widely present in SE standards such as "*enablers*" or "*control*" [2] are not distinguished from simple resources.

2.4. Proposed approach: principles, models and operational guide

The deployment of a given process in a company requires becoming able to model, verify and validate models mixing various views. By view, we mean "*a representation of a whole system or subsystem from the perspective of a single viewpoint*" [35]. Indeed actors in charge of a deployment would be able to consider simultaneously the process, the company, its objectives and constraints... without forgetting any aspect of the deployment. In the same time, these actors have to assess and improve interoperability capacities and aptitudes at the three levels of interoperability barriers of the entities involved during the deployment or into the process to deploy itself. The mixed view Systems Engineering (SE)/Enterprise Modelling (EM) shown in Figure 2 is inspired from GERAM [1]. On the right of this figure are illustrated the different EM contributions and on the left, the three classical views used in SE to define a system *i.e.* "*needs and requirements*", "*functional architecture and scenarios*" and "*organic architecture*". The views used in the proposed approach are defined in the centre of this figure.

Then, a methodological and technical set of tools has been designed and applied to assist companies in their deployment. For instance, a maturity model to assess company's readiness for the deployment is included in the proposed deployment approach (see Section 3). SE standards have been analysed and compared in order to help companies identify SE best practices, select the relevant standard to be respected, and establish AS-IS, TO-BE and IMPLEMENTATION processes models. BPMN 2.0 has been enriched following the previous remarks with a result still consistent with the language specification (see Section 4). Last the deployment approach based on the high-level management cycle defined in [43] is proposed enabling a tailoring of processes described in standards and considering the specific needs of the company (see Section 3). At the current stage of development, risks are not covered in the presented version of the approach. The latter must be applied in an iterative way: as any change in a company, highest process maturity cannot be reached in one shot! This approach leans on the definition of four specific processes illustrated in Figure 3 and is supported by a modelling workbench designed to be as open and compatible as possible (see Section 4)

Last, considering conceptual interoperability barrier requires defining the concepts along with their relationships and semantics in order to define a common communication basis [29][44] for all deployment stakeholders and between all actors who will be involved in the future process deployed. It would be also useful if this vocabulary could be available in all languages used in the company. To this end, a meta-model enriched with annotations including definitions in natural language along with their translations in both English and French is presented in Section 4. This meta-model is then automatically converted into an OWL ontology enabling to check its semantic consistency (see section 4).

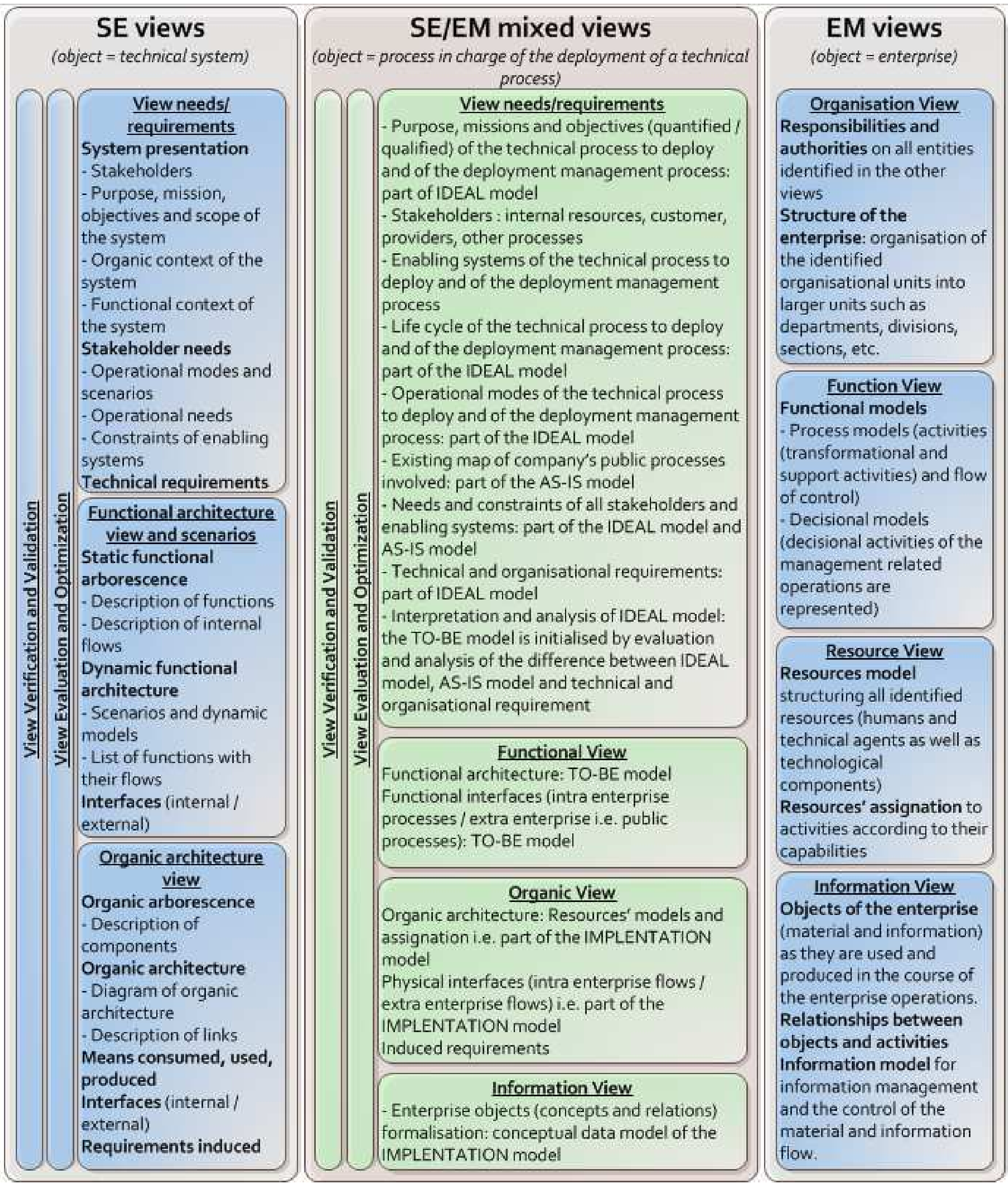


Figure 2: Mixed views to consider the process in charge of the deployment of a technical process

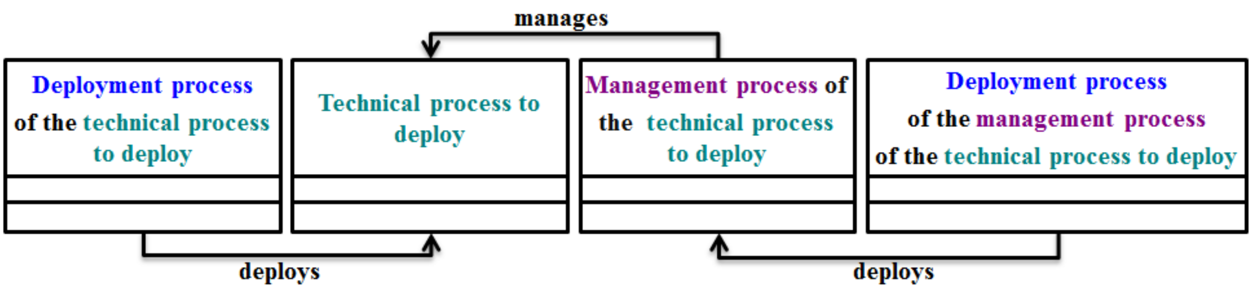


Figure 3: The four types of processes handled in the deployment

3. Practical details of the proposed deployment approach

This section details the proposed approach summarized by a three axis reference guide shown in Figure 4. The latter shows how the proposed models are designed, verified and validated and then used for the purpose of each proposed sub-processes coming from [43]. This is done by respecting the theoretical views illustrated and discussed in Figure 2. In the following, the focus is set on the preparation of the deployment and on its execution, so processes "manage" and "appraise" are not addressed.

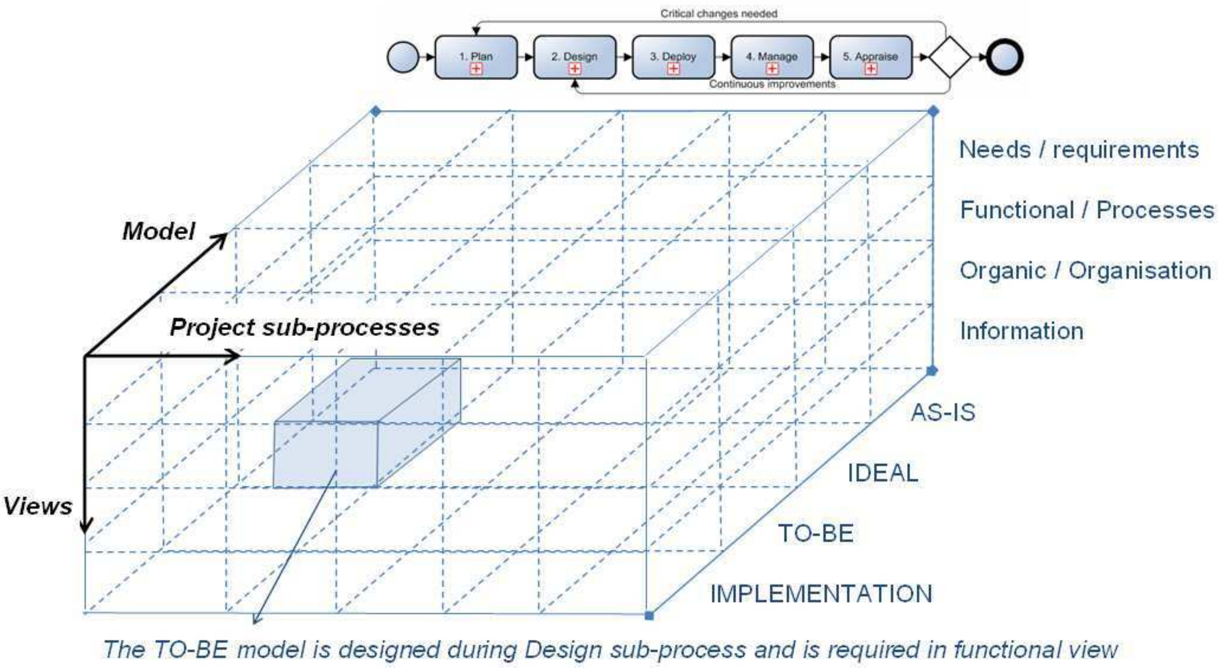


Figure 4: The three axes reference guide summarizing the approach

For this, all models are built taking into consideration the required standardization level of the modelling language, its acknowledgment in industry, the possibility to use existing modelling tools and to automate its use. So, as proposed, BPMN 2.0 has been chosen. To facilitate the reading, the main constructs of BPMN are summarized in Figure 5, and whenever they are mention in the text, they are written *in this police*.

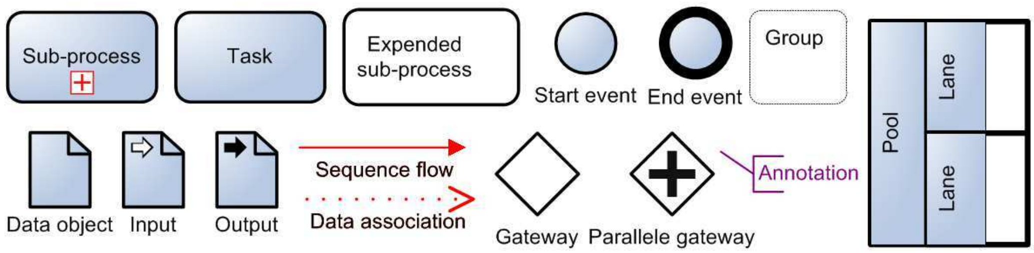


Figure 5: Constructs of BPMN 2.0 used in the proposed deployment approach

3.1. Sub-process "Plan"

BPMN 2.0 [36] defines three types of *activities*, *i.e.* of works that is performed within a *business process*: *task*, *sub-process*, and *call activity*. By definition, a *task* is atomic whereas a *sub-process* may include *sub-processes*, *tasks* or *call activities*. This section aims to detail the *sub-process* "*Plan*" which is the first one to be executed according to Figure 1. Its details are provided in Figure 6 and its first *sub-process* "*Define deployment inputs*" is detailed in Figure 7. It is strongly inspired by SE principles and particularly by the first activities of the *stakeholders' requirements definition process* promoted in SE standards.

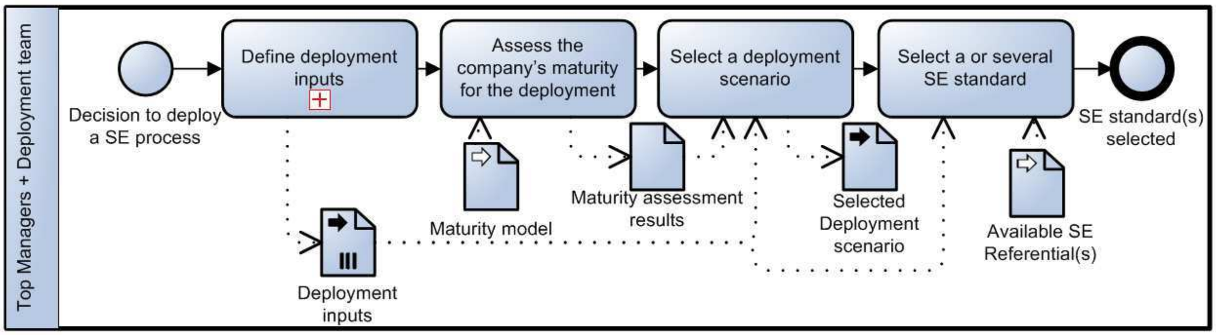


Figure 6: Sub-Process "Plan"

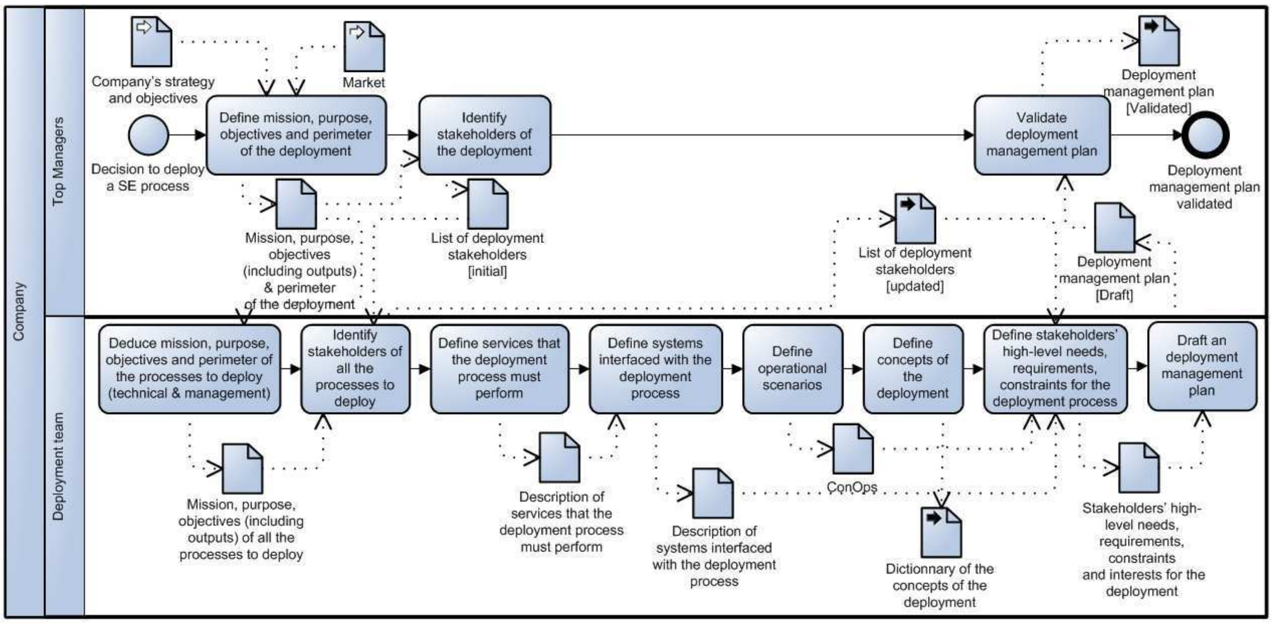


Figure 7: Sub-process "Define deployment inputs"

Then, once the company knows exactly what it intends to deploy, the second step is to assess its maturity to face a deployment. To this end, a maturity model is proposed in Appendix and will not be detailed much more in this paper. This maturity model has been designed to: 1) enable making an initial assessment of the company to track the progress achieved, 2) enable making managers and design stakeholders become aware of the maturity of the organization [30], 3) help to select priority improvement topics between possible ones, 4) enable choosing between possible deployment scenarios (summed up on Figure 8) according to company's maturity.

Finally, the *sub-process "Plan*" ends to pick one or several existing SE standards. To help companies with this selection work, available standards has been studied and their own strengths and weaknesses have been highlighted in the context of a helicopter manufacturer. Due to security constraints, this study cannot be presented but to illustrate this *task*, in our study [26] has been selected since it is an international industry standard. It has been completed with [42] and [2] since these handbooks provide application tips and details about documents to produce and that [42] takes into consideration certification constraints since it has been drafted for aerospace industry which is a business area close to aeronautic one.

	Results of maturity assessment			
Standardisation of design practices	Heterogenous practices		Homogeneous practices	
Readiness for (MB)SE	Not ready	Ready	Not ready	Ready
	Overview of scenarii			
Recommended deployment scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Application of the new process on new design projects	Recommended	Recommended	Recommended	Recommended
Application of the new process on existing design projects	Not recommended	Project dependent	Project dependent	Project dependent
Explicit mention of "SE", "process" and/or "modelling"	Not recommended	Recommended	Not recommended	Recommended
Translation of the new process into a methodology inspired from SE and promoting modelling	Recommended	Recommended	Recommended	Recommended

EASINESS OF DEPLOYMENT

Figure 8: Overview of proposed deployment scenarios

3.2. Sub-process "Design"

This second *sub-process* aims to build iteratively the TO-BE and IMPLEMENTATION models of all processes that should be deployed, that is to say: the technical process to deploy, its management process and their both deployment processes. This *sub-process* is modelled in Figure 9.

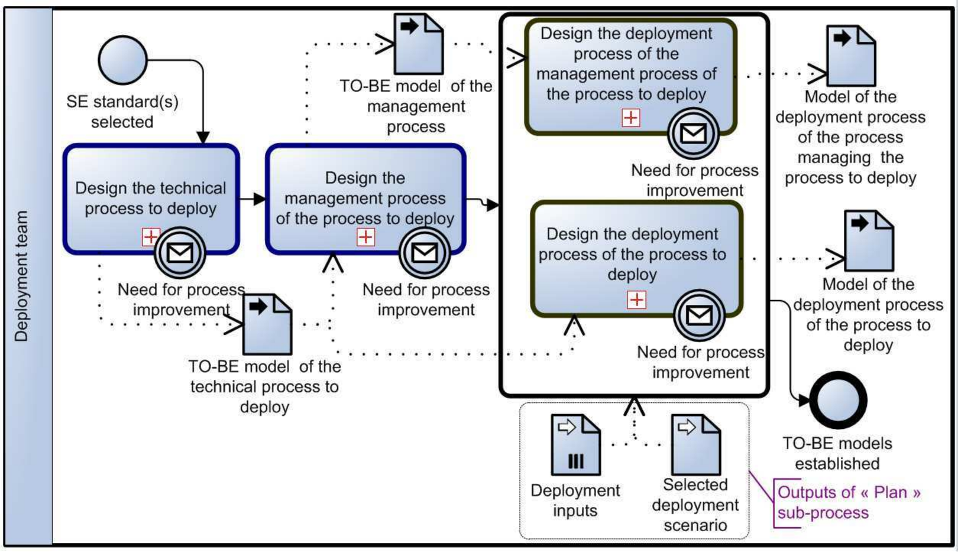


Figure 9: Sub-process "Design"

This figures shows events placed on the border of activities represented in bolded lines. It means that the activities are all triggered when an event is received. These are then *call activities*, *i.e.* a wrappers for globally defined *Sub-Processes* or *Tasks* that are reused in the current process [36]. The first *call activity* called "*Design a (technical or management) process*" is detailed in Figure 10.

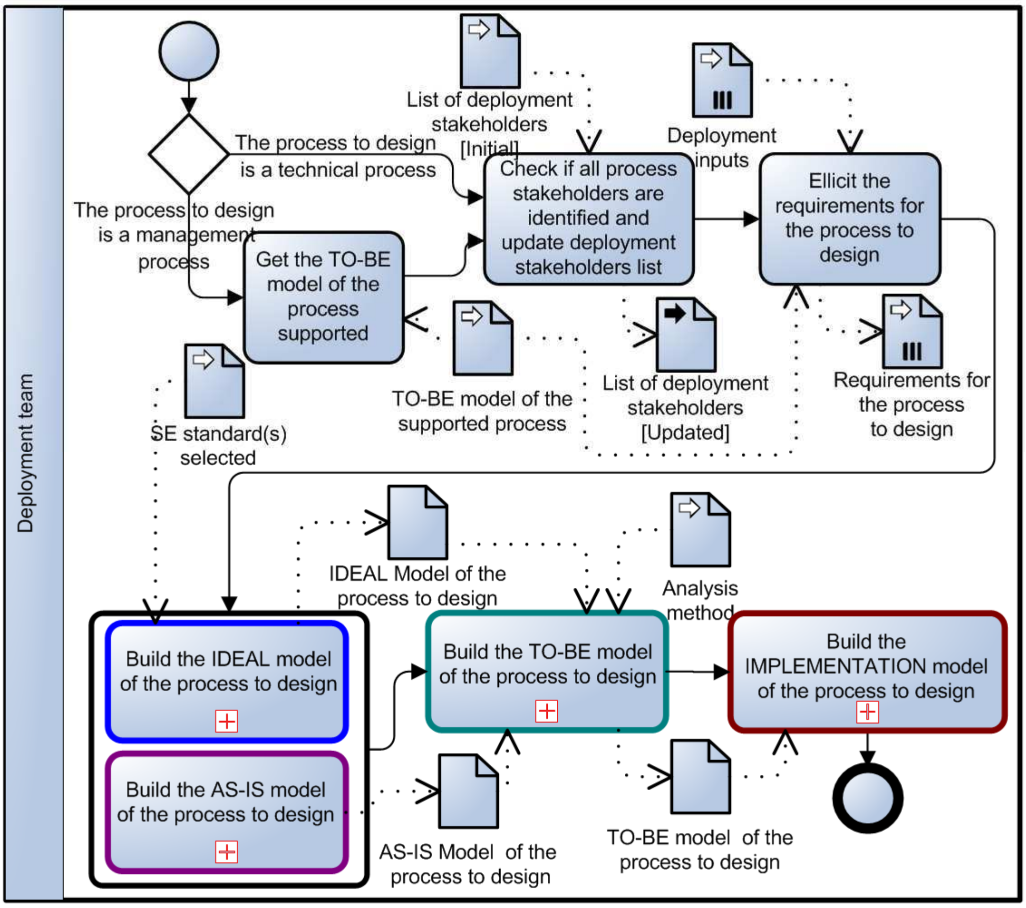


Figure 10: Call activity "Design a (technical or management) process"

This *call activity* includes itself four other *call activities* detailed as follows:

- Build the IDEAL model of the process to design (Figure 11). The IDEAL model is a model that we have defined in order to complete the three existing models already defined in enterprise modelling (AS-IS, TO-BE and IMPLEMENTATION models). Indeed, this model is defined in order to represent the "canonical" vision of the process to deploy *i.e.* the one described in the SE standard(s) selected but adapted to consider the specificities of the business area (such as aeronautics constraints and regulations for a helicopter manufacturer). Here IDEAL does not mean that we pretend that it is THE unique optimal solution but only that it is the goal that the company wants to reach. With this model, we do not aim to plan everything since we know that is just impossible, but we aim to provide companies with a "tool" enabling the sharing of some best practices that the company could adopt. It should be seen as a communication vector and thus as way to improve interoperability during the deployment. Figure 11 provides details about this *call activity*. The specific *gateways* of this figure are *Exclusive Event-based Gateway*. They mean that each occurrence of a subsequent *event* starts a new process instance [36]. In addition, the specific events with an envelope indicate *intermediary events catching messages*.

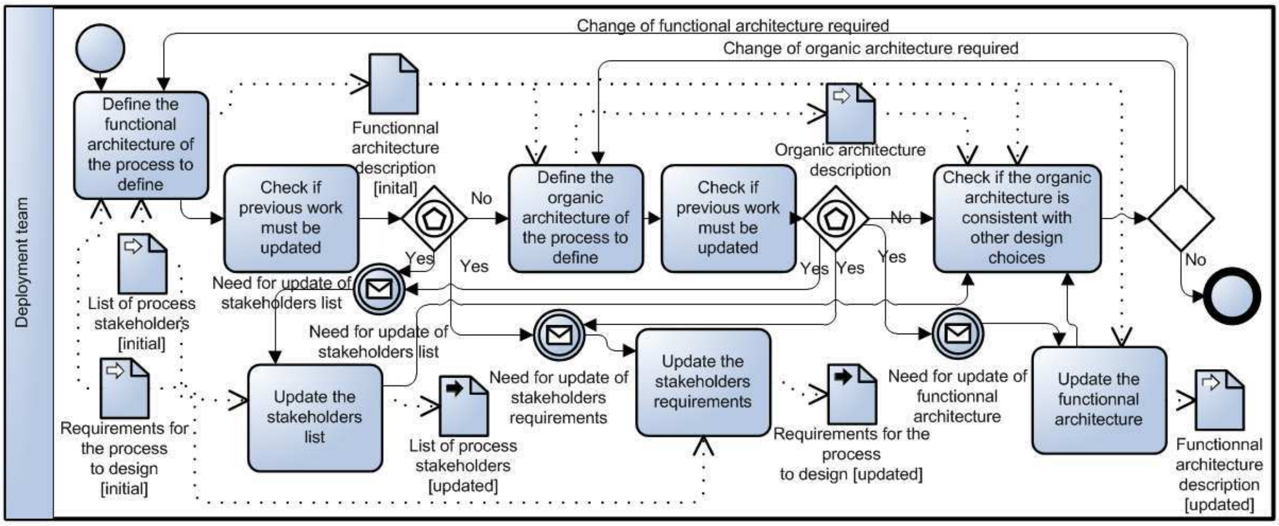


Figure 11: Call activity "Build the IDEAL model of the process to design"

- Build the AS-IS model of the process to design (Figure 12). This model, if it exists in the company, represents its current organization to perform the activities included in the process to deploy. As every model, it cannot represents the "whole" reality but when the company makes the effort to build it, the results constitutes a first formalization of the way the activities are performed and thus, it is a support for discussion and support of training for company's new comers. Moreover, this model is a first way to capture the vocabulary of the company which may be different form the one used in standards. If the deployment team is aware of some vocabulary conflicts, it may anticipate semantic interoperability problems that could occur during the deployment.

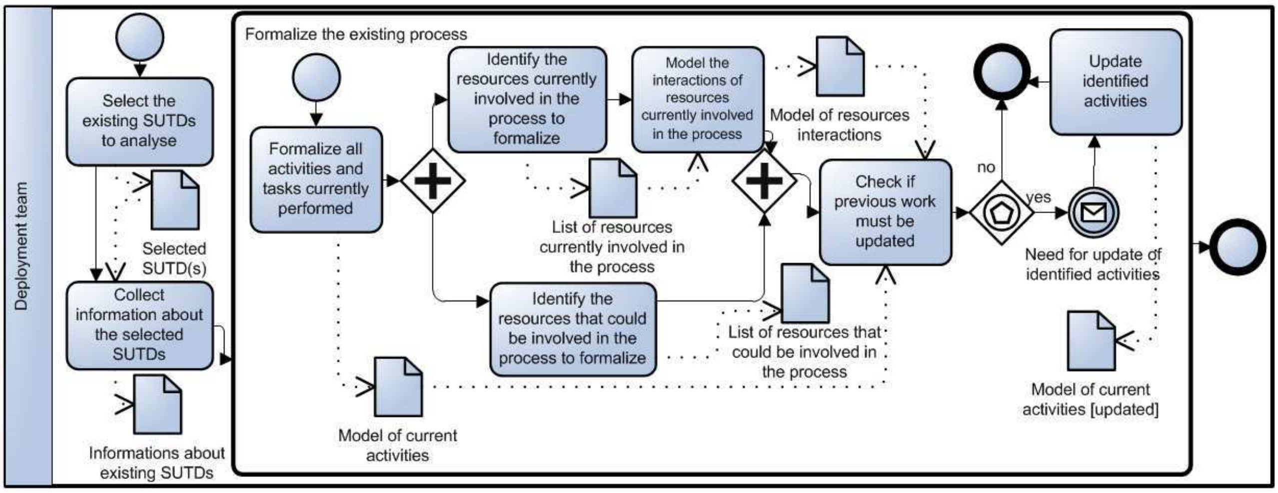


Figure 12: Call activity "Build the AS-IS model of the process to design"

- Build the TO-BE model of the process to design (Figure 13). This model should share the trade-off found between the IDEAL and the AS-IS model from a functional point of view. Interactions and roles should be explicitly defined.

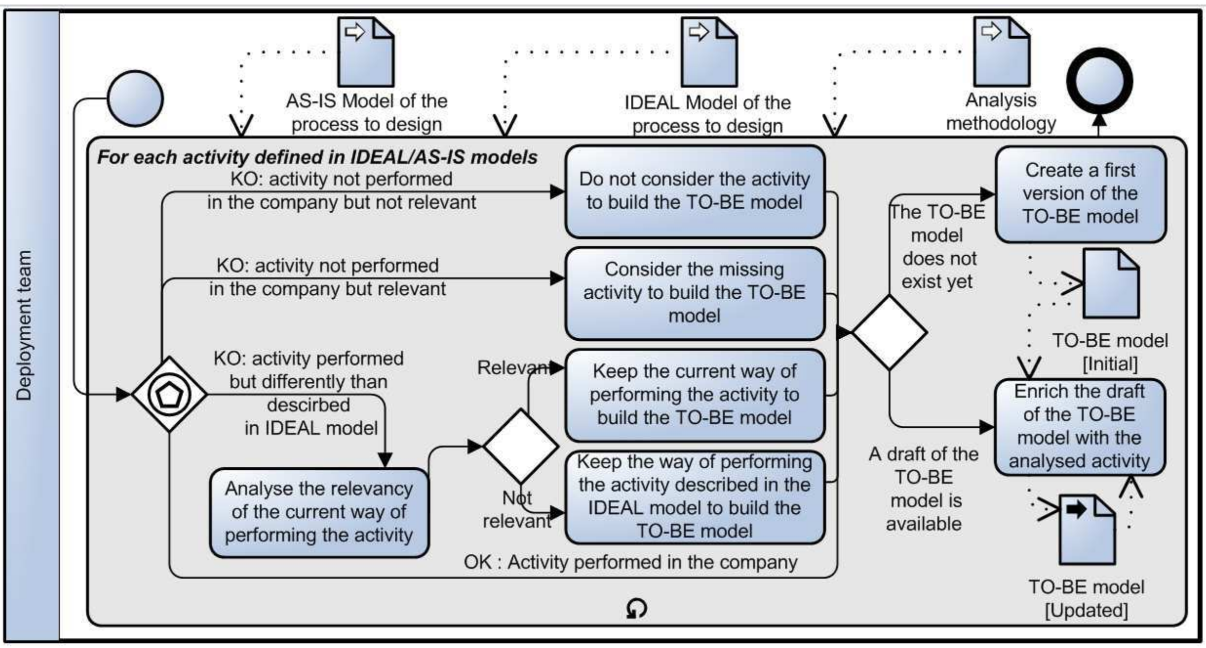


Figure 13: Call activity "Build the TO-BE model of the process to design"

- Build the IMPLEMENTATION model of the process to design (Figure 14). The development of this model considers the interoperability assessment of its resources [13][19][10][17][6][31][48]. The resulting model should be detailed enough to be directly applied by the members of the design office. Resources should be identified to play the roles previously identified in the TO-BE model.

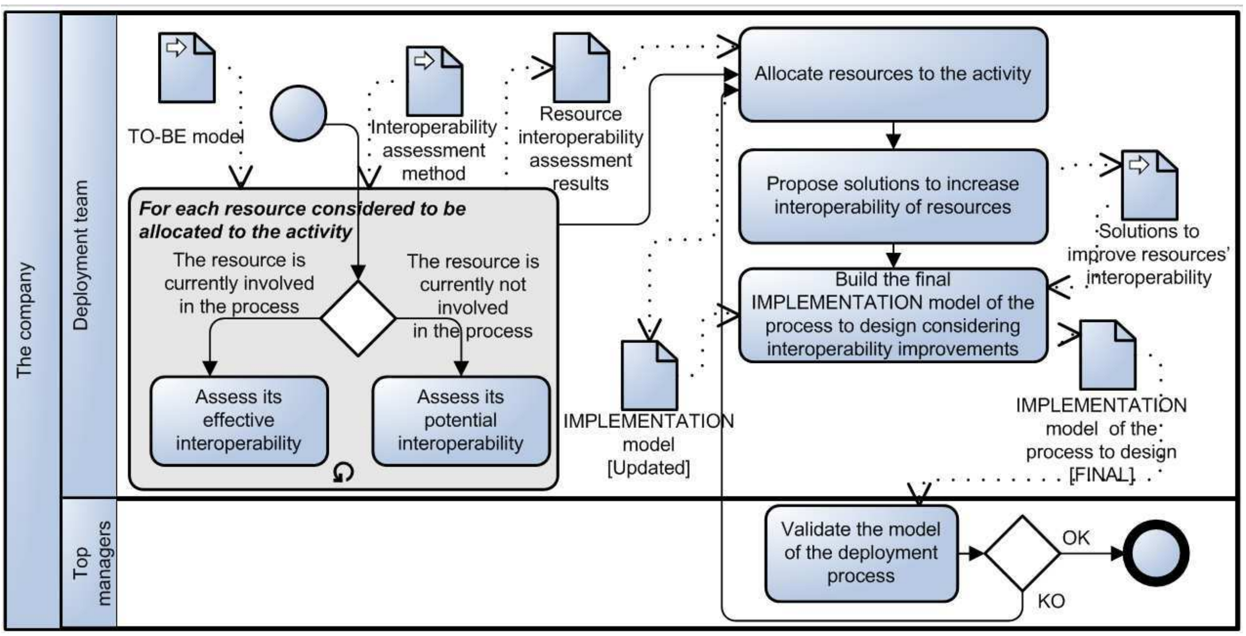


Figure 14: Call activity "Build the IMPLEMENTATION model of the process to design"

Once the design of a technical or management process to deploy is done, Figure 9 indicates that deployment processes should be defined. The required activities are then defined in Figure 15. A deployment process could for example include the activities defined in Figure 16.

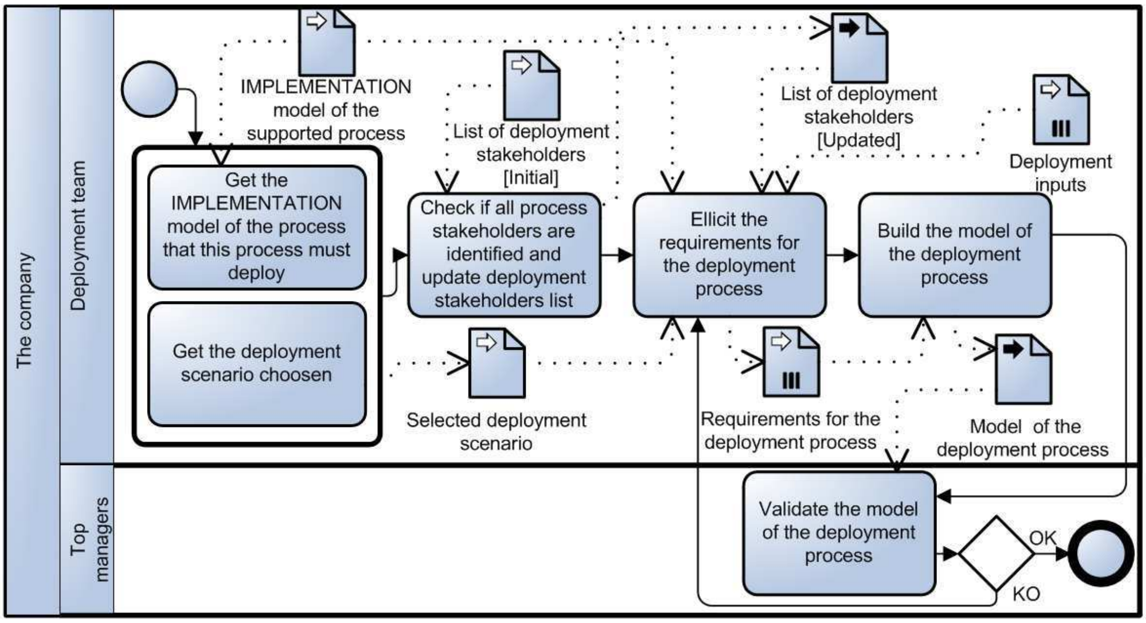


Figure 15: Call activity "Design a deployment process"

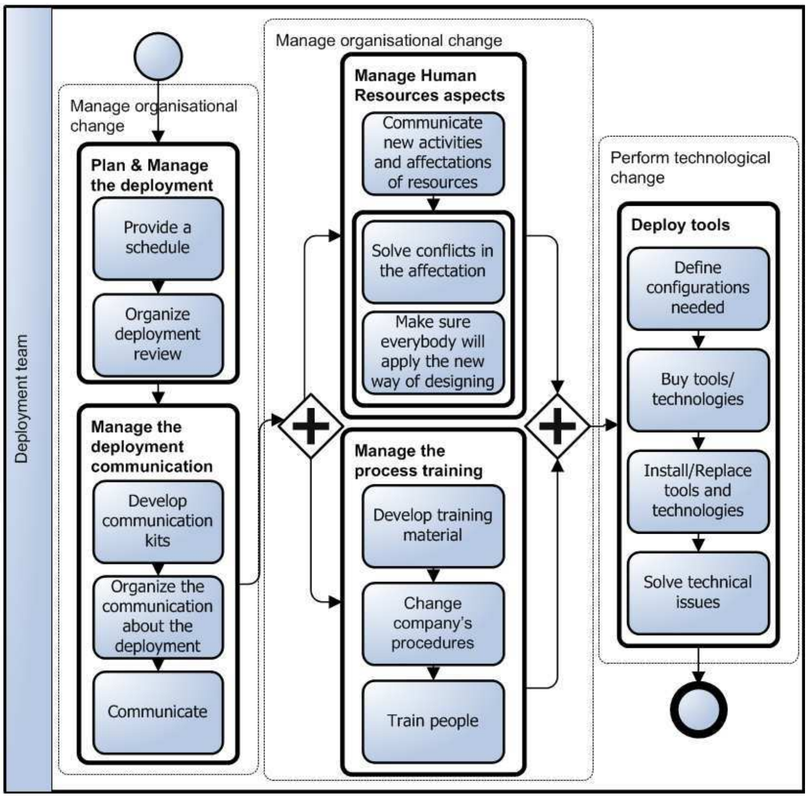


Figure 16: Generic deployment process

3.3. Sub-process "Deploy"

The third sub-process of the approach is concerned with deploying the previously defined processes. It is summed up in Figure 17. The components of the modelling environment to support this approach can be now introduced.

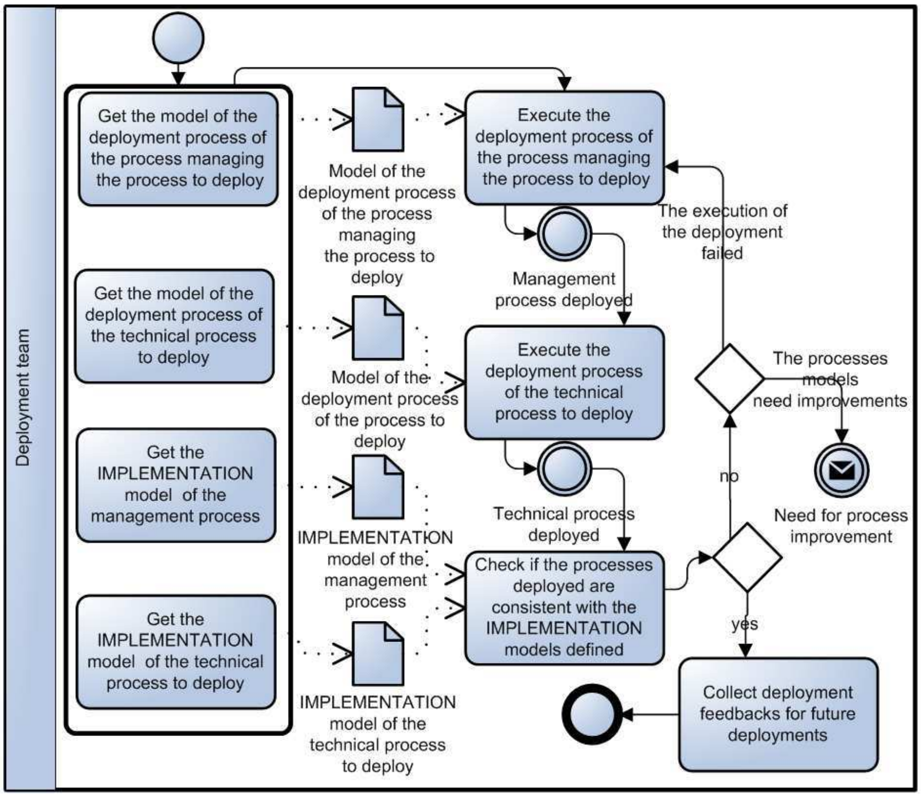


Figure 17: Sub-process “Deploy”

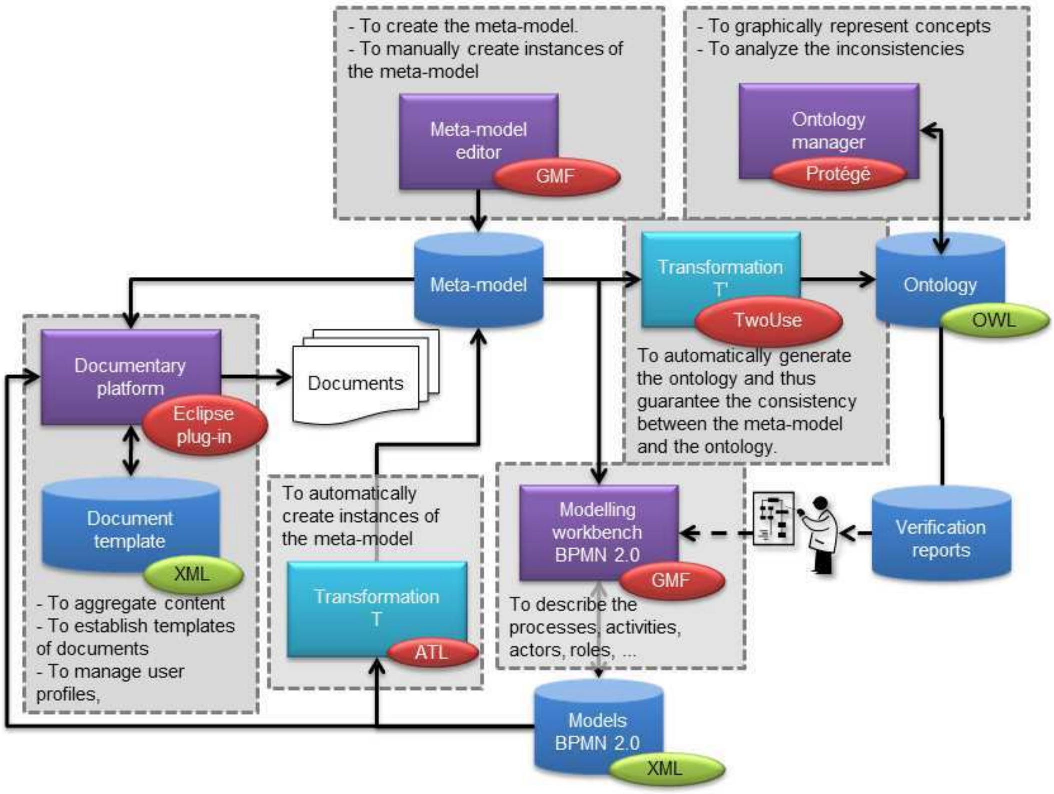


Figure 18: Overview of the modelling framework

4. A modelling framework to support the deployment approach

A full modelling framework has been designed in order to support modelling and analysis of processes and activities. It has to be as interoperable and as open-ended as possible. An overview of this framework is provided in Figure 18. It includes: a conceptual heart made of a meta-model and an ontology, a modelling workbench and a documentary platform.

4.1. Deployment meta-model

The approach to prepare and execute the deployment of Systems Engineering (SE) processes involves a lot of concepts *e.g.* resource, process, activity, stakeholders, etc. These concepts must be defined as soon as possible in order to facilitate and to guide the work of the deployment team. Indeed, having a common repository of concepts and of relationships between concepts enables a common understanding of each concerned actor and supports the work to be done with all stakeholders involved in the deployment project, especially if they come from different business fields. By defining explicitly these concepts, their semantic relationships, the deployment team reduces then the risks of misunderstandings and increases thus the potential and effective interoperability between these stakeholders [48][44][29]. In this research work, these concepts and relations are gathered in a meta-model described by using a class diagram from UML (Unified Modeling Language) since it is a very popular language enabling thus a quick understanding of most of stakeholders. The deployment team uses this meta-model as a guide for the modelling: any mandatory attributes defined in the meta-model must be included in the model and only relationships described in the meta-model can be used.

However, the definition of classes and relationships between them is not always sufficient to make the modeller understand and use properly concepts and relationships between them. A textual annotation is then added in the meta-model for each entity. The latter is defined in both English and French to take into account the multi-cultural nature of the helicopter manufacturer. In the same way, all names of classes and relationships are defined in both languages. The adopted system of annotations makes the meta-model open-ended: the company may add new annotations without limitations. Figure 19 shows an example of annotation.

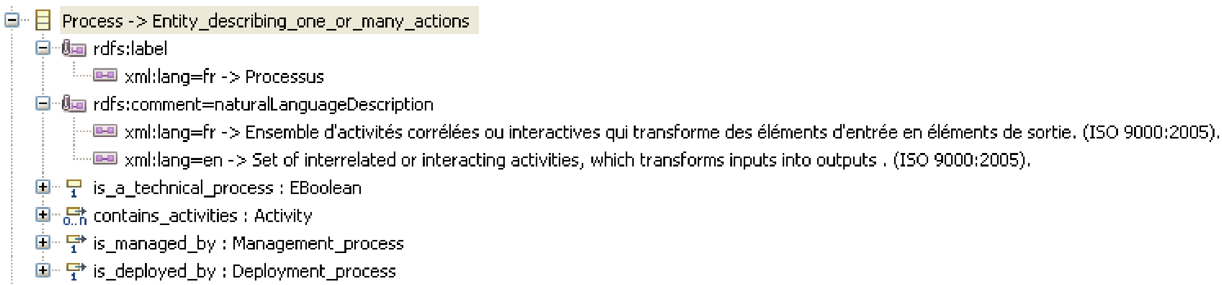


Figure 19: Example of annotations in the meta-model

By using the TwoUse [3] plugin of Eclipse, the meta-model is translated into an OWL ontology *i.e.* "*a formal, explicit specification of a shared conceptualization*" [18]. This enables the verification of the semantic consistency of classes and their instances thanks to reasoning tools. Indeed, they enable handling and making queries to the obtained ontology. Furthermore, an ontology enables switching between the languages used in the meta-model in a very quick and easy way. Here again, the final purpose is to increase conceptual interoperability. Let us notice that the meta-model and thus the ontology may evolve or be adapted according to the results of their application in a given company.

4.2. Modelling workbench

It appears that BPMN 2.0 used in modelling activities suffers from semantic gaps when compared to other languages like the Event-driven Process Chains (EPC) from the ARIS method [38] which, for instance, clearly describes the notion of "Role". This is due to its purpose: the first goal of BPMN is not to build conceptual model but to enable process model execution especially thanks to the Business

[3] See http://code.google.com/p/twouse/

Process Execution Language (BPEL) [33]. Thus, even if BPMN appears to be particularly interesting in our context, it requires enriching it conceptually with all necessary elements without introducing semantic or syntactic inconsistencies with BPMN 2.0 language specifications [36]. So the addition of new attributes of existing classes has been privileged. One example of enrichment is the possibility to make the distinction between simple inputs and controls flows. To that end, an attribute `isControl` has been added to the definition of BPMN *input*. In the same way, to distinguish enablers from *inputs*, attribute `isEnabler` has been added. Graphically, *inputs*, controls and enablers can be now distinguished as represented on Figure 20. Furthermore, to make the distinction between roles and resources which are both modelled with *pools* and *lanes*, attributes `poolType` and `laneType` has been respectively added to *Pool* and *Lane* and value "Role" or "Resource" according of their nature. Finally, an attribute `rolePlayed` enables indicating that a Resource plays a specific role selected in a pre-existing list of role names.

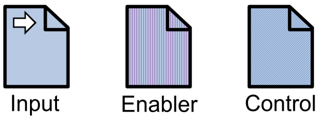


Figure 20: Graphical distinction between inputs, enablers and controls

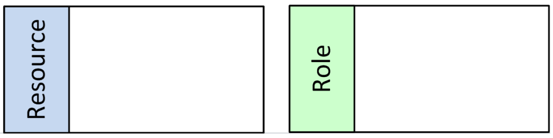


Figure 21: Graphical distinction between resource and roles

This modelling language is implemented in a modelling workbench created using the Graphical Modelling Framework (GMF) plug-in of Eclipse. This tool has been chosen for the help it brings in the insurance of the models' consistency.

5. Conclusion

This paper aims to provide practical answers to difficulties inherent in the deployment of Systems Engineering (SE) processes in large companies. To this end, Enterprise Modelling (EM) domain provides various concepts, means and at last real solutions very helpful for this deployment that should however be adapted to the SE context. This adaptation concerns particularly modelling languages, modelling frameworks and interoperability problem solving. This paper summarizes how deployment needs can be then carried out by mixing SE and EM disciplines *i.e.* how various existing works and contributions from both SE and EM enable us to provide solutions to meet them. The proposed deployment approach is then detailed and formalized. A software and conceptual framework supporting this approach is also presented. It includes: 1) a meta-model coupled with an ontology to define concepts and relationships used in the modelling, 2) an extension of BPMN 2.0 to consider specific needs of SE such as distinctions between inputs, controls and enablers, or interoperability needs such as the clear definition of roles and responsibilities played by resources and 3) a modelling workbench designed with the Graphical Modelling Framework plug-in of Eclipse. The perspectives of this work remain numerous. For instance, the current version of the approach presented in the paper does not take into account verification and validation (V&V) tasks. Indeed, it is absolutely necessary to help stakeholders involved in the deployment to check the relevance and the coherence of the proposed models or to evaluate the potential reached performances. In the same way, all the conceptual and technical tools are currently tested by a helicopter manufacturer enabling finally improving and validating the approach.

6. Bibliography

[1] GERAM: Generalised enterprise reference architecture and methodology - version 1.6.3. IFIP-IFAC Task Force, 1999. URL http://www.ict.griffith.edu.au/~bernus/taskforce/geram/versions/geram1-6-3/v1.6.3.html. Last accessed: 28.10.11.

[2] Systems engineering handbook - A guide for system life cycle processes and activities - v3.2. INCOSE, January 2010. URL http://www.incose.org/ProductsPubs/products/sehandbook.aspx.

[3] ISO/DIS 11354-1 - Advanced automation technologies and their applications - Part 1: Framework for enterprise interoperability. International Organization for Standardization, 2010. URL http://www.iso.org/iso/catalogue_detail.htm?csnumber=50417.

[4] AFIS. Ingénierie système - pourquoi ? comment ? Technical report, Association Française d'Ingénierie Système, 2005. URL http://www.afis.fr/default.aspx. [in French].

[5] S. Arnold. *Transforming systems engineering principles into integrated project team practice*. PhD thesis, Cranfield university, 2008. URL https://dspace.lib.cranfield.ac.uk/handle/1826/3033. Last access: 28.10.11.

[6] ATHENA. Deliverable D.A1.4.1 - framework for the establishment and management methodology. Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Application, 2005. URL http://interop-vlab.eu/ei_public_deliverables/athena-deliverables/A1/d-a1-4.1/attachment_download/file. Last access: 28.10.11.

[7] V. Bischoff, T. Huschke. Process management lifecycle (PML). 2008. URL http://-www.sdn.sap.com/irj/scn/index?rid=/library/uuid/207b0a14-fa2a-2b10-bf8f-b75b71d55b5f. Last access: 28.10.11.

[8] BNAE. RG AERO 000 40 A - General recommendation for the programme management specification. Bureau de Normalisation de l'Aéronautique et de l'Espace, 1999. URL http://-www.bnae.asso.fr/.

[9] BNAE. RG AERO 000 77 - Programme management - Guide for the management of systems engineering. Bureau de Normalisation de l'Aéronautique et de l'Espace, 2005. URL http://-www.bnae.asso.fr/.

[10] C4ISR. Levels of information systems interoperability (LISI). Technical report, C4ISR, 1998. URL http://www.eng.auburn.edu/~hamilton/security/DODAF/LISI.pdf. Last access: 28.10.11.

[11] CEA. Méthode sagace: le systémographe - Version 1.0 [in french]. CEA, 1999. [in French].

[12] V. Chapurlat and C. Braesch. Verification, validation, qualification and certification of enterprise models: Statements and opportunities. *Computers in Industry*, 59 (7): 711 – 721, 2008. ISSN 0166-3615. doi: DOI: 10.1016/j.compind.2007.12.018. URL http://www.sciencedirect.com/science/-article/B6V2D-4SG54Y3-1/2/dff655055a5b67c9dcfb7766e31f22d5. Enterprise Integration and Interoperability in Manufacturing Systems.
[13] N. Daclin. *Contribution au développement d'une méthodologie pour l'interopérabilité des entreprises*. PhD thesis, Université Bordeaux 1, 2007. [in French].
[14] ECSS. ECSS-E-ST-10C - Space engineering - System engineering general requirements. European Cooperation on Space Standardization, 2009. URL http://www.inpe.br/twiki/pub/Main/-GerenciamentoProjetosEspaciais/ECSS-E-ST-10C%286March2009%29.pdf. Last access: 28.10.11.
[15] EIA. ANSI/EIA-632-1998 (R2003) - processes for engineering a system. Electronic Industries Alliance, 1999. URL http://sunset.usc.edu/research/COSYSMO/ref_632.pdf. Last access: 28.10.11.
[16] J. Euzenat. Towards a principled approach to semantic interoperability. In *Proceedings of the IJCAI-01 Workshop on Ontologies and Information Sharing Seattle, USA, August 4-5, 2001.*, 2001. URL http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.14.3137&rep=rep1&type=pdf. Last access: 28.10.11.
[17] T. Ford, J. Colombi, S. Graham, and D. Jacques. The interoperability score. In *CSER - Conference on systems engineering research*, 2007. URL http://www.stevens-tech.edu/ses/seem/-fileadmin/seem/Proceedings_PDF/27.pdf. Last access: 28.10.11.
[18] T. Gruber. A translation approach to portable ontology specifications. *Knowledge acquisition*, 5: 199–199, 1993. ISSN 1042-8143. URL http://tomgruber.org/writing/ontolingua-kaj-1993.htm. Last access: 28.10.11.
[19] W. Guédria, D. Chen, and Y. Naudet. A maturity model for enterprise interoperability. In *R. Meersman, P. Herrero, and T. Dillon (Eds.): OTM 2009 Workshops*, pages 216–225, 2009. URL http://www.springerlink.com/content/p0w116875089307h/.
[20] P. Harmon. *Business process change: a manager's guide to improving, redesigning, and automating processes*. The Morgan Kaufmann Series in Data Management Systems. Morgan Kaufmann Publishers, 2003. ISBN 9781558607583.
[21] J. B. Hill, J. Sinur, D. Flint, and M. J. Melenovsky. Gartner's position on business process management. Technical report, Gartner, 2006. URL http://sites.google.com/site/downloadsap5/-136533.pdf. Last access: 28.10.11.
[22] IDS Scheer. Business process management: Aris value engineering - concept. Technical report, IDS Scheer, 2005. URL http://www.sdn.sap.com/irj/scn/go/portal/prtroot/docs/library/uuid/eae8e311-0b01-0010-0f9c-8d26e2714a91?QuickLink=index&overridelayout=true. Last access: 28.10.11.
[23] IEEE. IEEE 1220:2005 - Standard for application and management of the systems engineering process. Institute of Electrical and Electronics Engineers, 2005. URL http://standards.ieee.org/-findstds/standard/1220-2005.html.
[24] INTEROP-NoE. Deliverable DI.2 - enterprise interoperability-framework and knowledge corpus-advanced report. Interoperability Research for Networked Enterprises Applications and Software project, 2006. URL http://interop-vlab.eu/ei_public_deliverables/interop-noe-deliverables/di-domain-interoperability/di-2-enterprise-interoperability-framework-and-knowledge-corpus/-attachment_download/file. Last access: 28.10.11.
[25] ISO/IEC. ISO/IEC TR 19760:2003 - Systems engineering - A guide for the application of iso/iec 15288 (system life cycle processes). International Organization for Standardization, 2003. URL http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=33898.
[26] ISO/IEC. ISO/IEC 15288:2008 - Systems engineering - System life cycle processes. International Organization for Standardization, 2008. URL http://www.iso.org/iso/-catalogue_detail?csnumber=43564.
[27] ISO/IEC. ISO/IEC TR 90005:2008 - Systems engineering - Guidelines for the application of iso 9001 to system life cycle processes. International Organization for Standardization, 2008. URL http://-www.iso.org/iso/catalogue_detail?csnumber=41553.
[28] ISO/IEC. ISO/IEC TR 24766:2009 - Information technology - Systems and software engineering - Guide for requirements engineering tool capabilities. International Organization for Standardization, 2009. URL http://www.iso.org/iso/iso_catalogue/catalogue_tc/-catalogue_detail.htm?csnumber=51041.

[29] L. A. Kappelman. Brindging the chasm. *Architecture Governance*, 3: 28, 2007. doi: 10.1007/978-3-642-15654-0_2. URL http://www.springerlink.com/content/h1mv674qn2425632/.
[30] J. P. Kotter. Leading change why transformation efforts fail. *Harvard Business Review*, 2006.
[31] M. Leite. Interoperability assessment. 1998. URL http://www.dtic.mil/cgi-bin/-GetTRDoc?AD=ADA350577&Location=U2&doc=GetTRDoc.pdf. Last access: 28.10.11.
[32] S. Mathieu. *Comprendre les normes ISO 9000: version 2000*. AFNOR, 2002. ISBN 9782124650651. [in French]
[33] OASIS. Web services business process execution language version 2.0. OASIS, 2007. URL http://docs.oasis-open.org/wsbpel/2.0/wsbpel-v2.0.pdf. Last access: 28.10.11.
[34] OMG. Software & systems process engineering metamodel specification (SPEM) version 2.0. OMG, 2008. URL http://www.omg.org/spec/SPEM/2.0/. Last access: 28.10.11.
[35] OMG. Omg systems modeling language, version 1.2. Object Management Group, 2010. URL http://www.omg.org/spec/SysML/1.2/. Last access: 28.10.11.
[36] OMG. Business process model and notation (bpmn) version 2.0. OMG, 2011. URL http://-www.omg.org/spec/BPMN/2.0/. Last access: 28.10.11.
[37] S. ROCHET. *Formalisation des processus de l'Ingénierie Système : Proposition d'une méthode d'adaptation des processus génériques à différents contextes d'application*. PhD thesis, Université de Toulouse, 2007. URL http://eprint.insa-toulouse.fr/archive/00000162/01/Rochet.pdf. Last access: 28.10.11. [in French].
[38] A.-W. Scheer. *Architecture of Integrated Information Systems*. Springer, 1992.
[39] S. Sheard. Three types of systems engineering implementation. In *Tenth International Symposium of the International Council on Systems Engineering, Minneapolis, MN, July 2000*, 2000. URL http://www.3milsys.com/papers/00%203%20Types%20paper.pdf. Last access: 28.10.11.
[40] S. A. Sheard. Twelve systems engineering roles. In *Proceedings of INCOSE - 1996 INCOSE Symposium*, 1996. URL http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.23.6360. Last access: 28.10.11.
[41] S. A. Sheard. The frameworks quagmire. 1997. URL http://stsc.hill.af.mil/crosstalk/1997/sep/-frameworks.asp. Last access: 28.10.11.
[42] R. Shishko and R. Chamberlain. Nasa systems engineering handbook. National Aeronautics and Space Administration, December 2007. URL http://education.ksc.nasa.gov/esmdspacegrant/-Documents/NASA%20SP-2007-6105%20Rev%201%20Final%2031Dec2007.pdf. Last access: 28.10.11.
[43] A. Sienou. *Proposition d'un cadre métholodogique pour le management intégré des risques et des processus d'entreprise*. PhD thesis, Institut National Polytechnique de Toulouse, 2009. URL http://-ethesis.inp-toulouse.fr/archive/00000878/. Last access: 28.10.11. [in French].
[44] G. Simons, L. Kappelman, and J. Zachman. Enterprise architecture as language. *Complex Systems Design & Management*, pages 29–47, 2010. URL http://www.springerlink.com/index/-H1MV674QN2425632.pdf.
[45] A. ter Hofstede, W. van der Aalst, A. ter Hofstede, and M. Weske. Business process management: A survey. In M. Weske, editor, *Business Process Management*, volume 2678 of *Lecture Notes in Computer Science*, pages 1019–1019. Springer Berlin / Heidelberg, 2003. ISBN 978-3-540-40318-0. doi: http://dx.doi.org/10.1007/3-540-44895-0_1. URL http://www.springerlink.com/content/-9yh5wyawlwv20uae/.
[46] USDT. Systems engineering guidebook for intelligent transportation systems. US Department of Transportation, 2009. URL http://www.fhwa.dot.gov/cadiv/segb/. Last access: 28.10.11.
[47] F. Vernadat. *Enterprise modeling and integration: principles and applications*. Kluwer Academic Publishers, 1996.
[48] E. Yahia. *Contribution à l'évaluation de l'interopérabilité sémantique entre systèmes d'information d'entreprise : Application aux systèmes d'information de pilotage de la production*. PhD thesis, Université Henri Poincaré - Nancy I, 2011. URL http://tel.archives-ouvertes.fr/tel-00630118/fr. Last access: 28.10.11 [in French].
[49] M. Zur Muehlen. *Workflow-based Process Controlling. Foundation, Design, and Application of workflow-driven Process Information Systems*. 2004. URL http://www.bpm-research.com/download/-book/Michael_zur_Muehlen_-_Workflow-based_Process_Controlling_%28Web-Small%29.pdf. Last accessed: 28.10.11.

Appendix: a maturity model to assess the readiness to face a deployment

	Maturity Level	1 - Initial	2 - Low	3 - Neutral	4 - Good	5 - Excellent
	Catch phrase	"SE!? What is it?!?"	"SE? No use to deploy it, we already apply its principles"	"SE is great but we are not ready for it in our company"	"SE:why not ?"	"SE : Let's go !"
PEOPLE	**Available skills within the company**					
	Skills - Theory of SE (MBSE, standards)	SE is not known	SE generally unknown or misunderstood (and misapplied)	SE is generally known, but its application is not considered in the company	Relevance of SE is accepted and understood locally	Relevance of SE is accepted and understood in the whole company
	Skills - Modelling (to perform process modeling and modelling activities required by MBSE)	Modelling practices and benefits are not known	Modelling principles generally unknown or misunderstood (and misapplied)	Modelling is generally known, but its application is not considered in the company	Relevance of Modelling is accepted and understood locally	Relevance of Modelling is accepted and understood is the whole company
	Skills - Project Management	PM is not known	PM generally unknown or misunderstood (and misapplied)	PM is generally known, but its full application could not be considered in the company (lack of skills)	Relevance of PM is accepted and understood locally. It could be fully applied at this level	Relevance of PM is accepted and understood in the whole company. It could be fully applied at this level
	Training to develop the skills required for the application of SE, MBSE and PM	No internal training			Internal training available but concerned people are not systematically trained	Internal training available and all concerned people are trained
	Validation of skills (acquired through training, education, professional experience)	The skills required to deploy SE are not identified or formalized			Roles required for SE application are defined, accepted and shared within the company. The required skills are clearly identified.	The skills required for the application of the SI claimed by members of the company (old or new hires) are evaluated
	Management and Leadership					
	Involvment of managers in the SE deployment project	Missing or not visible enough		Low	Middle management convinced and involved	Top management convinced and involved
	Vision of management (Design Strategy, Product Policy, Partnership Policy)	Missing or not visible enough		Clearly defined but not shared		Clearly defined and shared
	Division of tasks between departments / partners / (project - program)	Missing or not visible enough		Clearly defined but not shared		Clearly defined and shared
TSE PROCESSES	**Technical Processes (Technical design activities)**					
	Consistency/Standardisation of design practices among the projects (processes/activities, methods, tools, constraints, R & R)	Heterogeneous - Projects specific - No entity is responsible for standardizing the practices of the various projects			Standard - Common to all projects with a dedicated entity	
	Capitalization, formalization and sharing of knowledge and technical know-how about design (activities, resources, methods)	No formalisation	Some initiatives to capitalize on knowledge and technical know-how about design, but not disseminated	Some initiatives to capitalize on knowledge and technical know-how about design and disseminated within the company	Description of the standard design process (high level) - Circulation to all staff	Description of the standard design process (low level) and instantiation for each new project - Circulation to all staff
	Base for design activities	Document-based design		Initiatives of use of models complementary to the use of documents		Model-based design
	Readiness level for MBSE	Document-based design managed with difficulties - The company is not mature enough to apply the principles of MBSE and should focus on SE good practices.		Document-based design managed. Models are used in the appendix of official documents for the purpose of illustrations to illustrate the point of the authors.	Document-based design but some models are used not to illustrate documents but to apply MBSE principles	Full model-based design
	Project Processes (Project management)					
	Consistency/Standardisation of project management practices (processes/activities, standards, methods, tools, KPIs, milestones, deliverables, standards)	Heterogeneous - Project specific - Every project has its own practices independently from the others	Heterogeneous - Project specific - A referential is choosen in order to start to standardise PM practices		Standard - Common basis for all projects	
	Capitalization, formalization and sharing of know-how about the management of design projects	No formalisation		Descriptions of artifacts (documents / models + specs + reviews) used in some projects	High level description of the artifacts (documents / models + specs + reviews) used as standard	Low level description of the artifacts (documents / models + specs + reviews) used as standard
	Definition of interfaces / R & R / constraints of stakeholders all along design activities	None - No overview of collaborations	Implicit or not shared definition of interfaces between departments and R&R within theses departments	Formal, shared and applied definition of interfaces between departments and R&R within theses departments	Formal, shared and applied definition of standard R&R required during design activities	Standard definition of the constraints impacting each of the stakeholders in the design so that all are aware and can deal with
	Arbitration between project short-term vision and SE deployment long term vision	It is not possible to free up time to apply SE principles: the project constraints prevail over SE deployment			Begining of mind changes : the short-term constraints of project management and are not incompatible with SE deployement	Projects managers understand that PM and SE have the same ultimate project goal. and while being delivery-oriented, the PM will have to allocate time to the project members to apply SE principles
ESE PROCESSES	**Enterprise Systems Engineering Processes (Design Office improvement management)**					
	Existence of a team responsible for the design office practices standardization and overall improvement	Missing	Existing but not enough sized or lacking the necessary skills		Existing, fairly sized and maintained during the reorganization	
	Degree of formalisation (modelling) of the enterprise	No formal process	Defined processes but with a too high level of abstraction (level activity not detailed) - Design Office level	Processes and activities detailed but highly impacted by a change of organization - Project Level	Processes and activities detailed but highly impacted by a change of organization - Department level	Detailed processes and activities designed to easily monitor evolutions of the organization - Team level
	Standardisation of modeling practices (used to formalize the enterprise)	Modelling unused	No standard formalism / semantics		Shared formalism	Shared semantics
	Capacity to exchange and share information within the design office and its various entities (scale inspired from the LISI model)	Isolated systems (No connection)	Connected systems (Electronic connection) - Separate data & applications	Basic collaboration - Separate data and applications. Some shared data may exist but the sharing/search is difficult	Sophisticated collaboration - Shared data "Separate" applications	Advanced collaboration - Interactive manipulation - Shared data and applications
	Capacity to provide improvement all-inclusive improvement solutions (deliverable+ implementation methodology + training)	N/A	Solutions delivered but without providing their enablers		Complete solutions delivered	

SE : Systems Engineering — N/A: Not applicable — R&R : Roles et Responsabilities — MBSE : Model-based Systems Engineering — TSE : Traditional Systems Engineering — ESE : Enterprise Systems Engineering